International Mars Architecture for the Return of Samples (iMARS) Phase II: Findings and Recommendations

Caroline Smith, Tim Haltigin and the iMARS Phase II Working Group

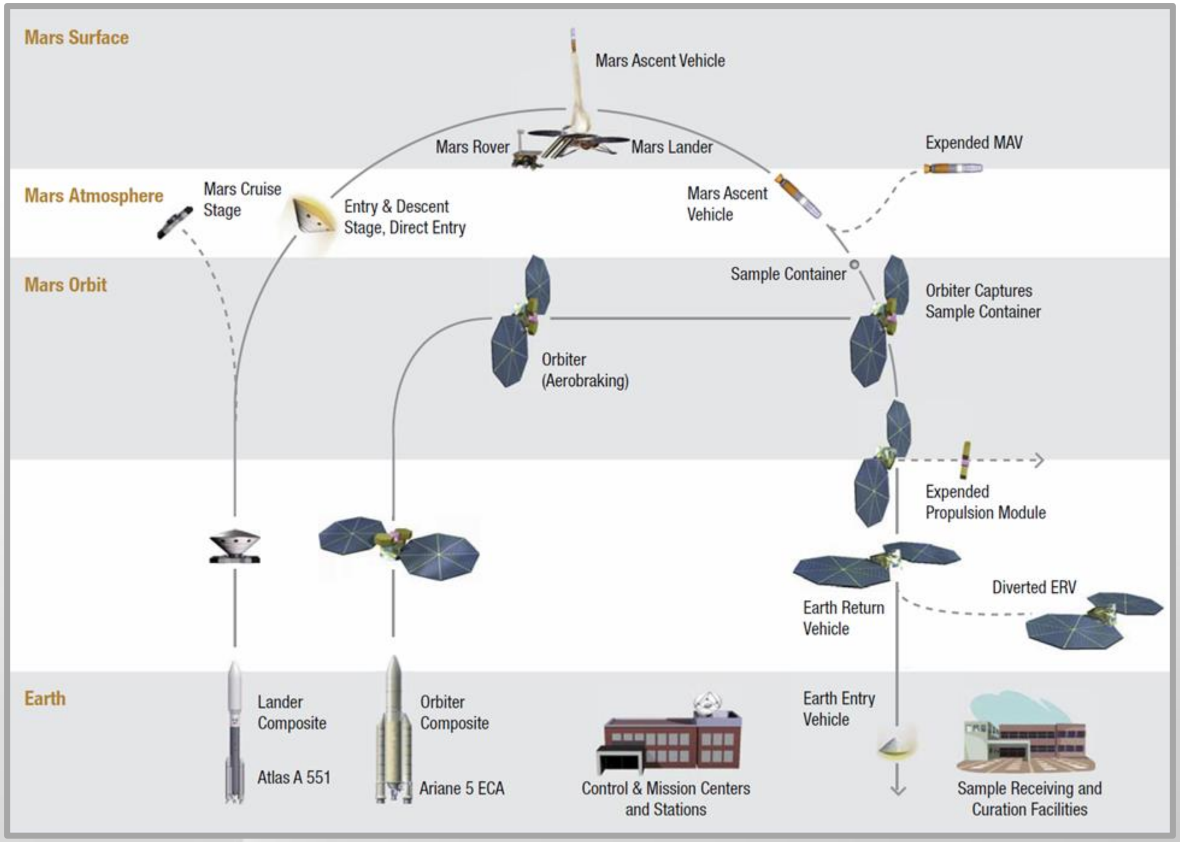
Mars Exploration Program Analysis Group – Silver Spring, MD, USA – March 2, 2016

1. Introduction

iMARS – Background

- **i**nternational **M**ars **A**rchitecture for the **R**eturn of **S**amples
- Originally chartered by IMEWG in 2006 to develop a plan for Mars Sample Return Mission Architecture
  - *IMEWG: International Mars Exploration Working Group*

iMARS Phase I – Reference Architecture



"2 + 1" approach highlights the importance of the post-return segment → ground operations are integral part of the mission

iMARS Phase I – Recommendations

"IMSI" Concept

- Multinational mission will require multinational coordination to accomplish
  - ***Need to define an International MSR Science Institute***

Distributed vs. On Site Needs

- Not everyone with an excellent science investigation would be able to work at the return facility
  - ***How do we keep the samples from becoming "stuck in containment?"***

iMARS Phase II: Statement of Task (Engineering)

"Propose a baseline implementation approach for MSR… identify[ing] critical challenges and opportunities."

Phase II Terms of Reference

International Mars Exploration Working Group (IMEWG)
Charter for the Reconstitution of an International Working Group On the Return of Samples from Mars

The iMARS work will support the International Mars Exploration Working Group (IMEWG):

- For Phase II, the iMARS working group will be organized into two subteams: a Science/Earth Operations Subteam and an Engineering Subteam. Each team will have its own chair.
- The members of each team will be nominated by the member states and agencies of IMEWG and the chairs appointed by the iMARS Steering Group;
- iMARS members will be scientists, engineers and technologists as appropriate; and
- The subteams shall complete the study within 12 months, with an interim report to IMEWG approximately halfway through the study. Goals for each subteam are articulated below.

Phase II Goal – Science Team: Develop a proposed Science Management Plan, including a concept for IMSI (International MSR Science Institute).

Background: The science side of MSR entails using returned samples to answer compelling scientific questions. Regardless of the flag under which a given mission is flown, the first-ever return of samples from another planet will be a global collaboration. There will be opportunities for international partners to participate in science-related activities such as the following:

- Formulation of the objectives and specific scientific hypotheses to be tested using the returned samples. Selection of specific investigations to be funded and performed
- Management of the returned sample collection, including setting requirements for handling and curation.
- Specification of measurements to be made on samples, including those needed for life detection and biohazard testing, under containment.
- Sample allocation decisions, including conduct of investigations under containment and release of samples either to additional containment facilities or to general labs.
- Sharing the scientific credit for major discoveries made on a group basis.

Based on developments since iMARS Phase I, the science team will presuppose successful identification and collection of a set of samples from a scientifically compelling site, for example, by the recently initiated NASA Mars 2020 mission. This team will develop the framework of a sample science management plan. The plan should address the potential international participation above and propose an international science management structure that would facilitate that participation. The management team is envisioned as an entity that would allow the international community to participate in returned sample science in a structured way. An International MSR Science Institute (IMSI) concept was proposed in 2008 by iMARS Phase I, and it was recommended for further definition in iMARS Phase II. The team should refer to the E2E-iSAG report for returned sample science objectives and the types of samples to be collected.

Statement of task:

1. Investigate a spectrum of potentially relevant institutes, and identify the attributes most relevant to the MSR situation. On the basis of this information, propose a set of organizing principles for sample science management.
   a) Consider how best to structure sample science management, either through the IMSI model or a new construct. It should have at least some virtual dimension to it (e.g., NASA Astrobiology Institute) to accommodate the geographic distribution of its stakeholders, along with any functional needs for a brick-mortar building (e.g., Space Telescope Science Institute).
2. Identify options and develop recommendations for:
   a) The leadership. How would this leadership be selected and rotate?
   b) Focus areas needed to effectively manage international participation in sample characterization and science.
   c) The size. How many people would need to be involved to have enough to organize sub-teams in the necessary different focus areas?
   d) Selection processes for the members of the institute.
   e) Potential funding mechanisms.
3. Propose the role the management team(s) would play in the following activities:
   a) Providing scientific strategic guidance and oversight for Mars Sample Return.
   b) Development and maintenance of the Sample Management Plan, including for example the sample-management rules and processes.
   c) Providing scientific oversight of the Sample Receiving Facility(ies) and curation facilities, including facility design, construction, and operation.
   d) Conduct of the preliminary sample examination and taking measurements for scientific and biohazard assessment purposes

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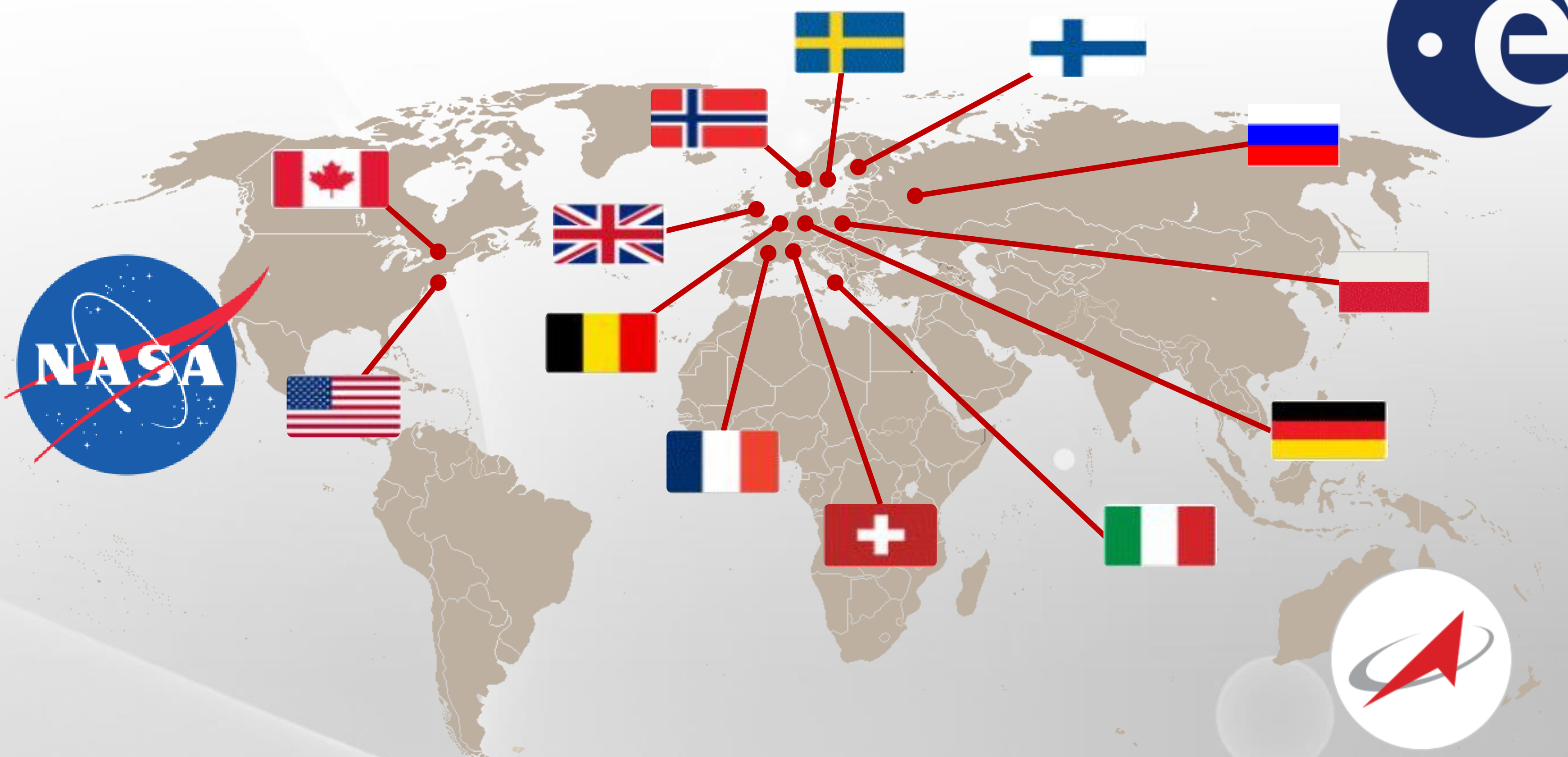
Roster

Steering Committee

Lisa May → Dave Lavery	Rolf de Groot	Lev Zelenyi



2. MSR Status and Assumptions

E2E-iSAG MSR Objectives (2011)

Priority	Objective Reference #	Objective Description
1	A1	Critically assess any evidence for past life or its chemical precursors, and place detailed constraints on the past habitability and the potential for preservation of the signs of life
2	C1	Quantitatively constrain the age, context and processes of accretion, early differentiation and magmatic and magnetic history of Mars.
3	B1	Reconstruct the history of surface and near-surface processes involving water.
4	B2	Constrain the magnitude, nature, timing, and origin of past planet-wide climate change.
5	D1	Assess potential environmental hazards to future human exploration.
6	B3	Assess the history and significance of surface modifying processes, including, but not limited to: impact, photochemical, volcanic, and aeolian.
7	C2	Constrain the origin and evolution of the martian atmosphere, accounting for its elemental and isotopic composition with all inert species.
8	D2	Evaluate potential critical resources for future human explorers.
ADDI-TIONAL	A2	Determine if the surface and near-surface materials contain evidence of extant life

Advances Since 2008

Technology	Mission	Applicability to MSR
Guided entry into Mars atmosphere	Mars Science Laboratory (NASA)	The spacecraft's descent into the martian atmosphere was guided by small rockets on its way to the surface, controlling the spacecraft's descent until the rover separated from its final delivery system, the sky crane. This landing technique allows landing larger and more capable rovers carrying more science instruments.
Sky crane terminal descent	Mars Science Laboratory (NASA)	With spacecraft velocity close to zero, the sky crane lowered the rover to the surface from the descent stage. At touchdown, the descent stage separated from the lander and flew away, allowing the landed system to begin its mission.
Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) for rovers	Mars Science Laboratory (NASA)	MMRTGs are a new generation of long-lived, reliable nuclear power systems ideally suited for missions involving autonomous operations in the extreme environments of space and on planetary surfaces. They reliably convert heat into electricity, generate power in increments (100+ Watt), optimize lifetime power levels (14+ years), minimize weight and ensure a high degree of safety.
Drilling	Mars Science Laboratory (NASA) ——— Rosetta/Philae (ESA)	MSL's Powder Acquisition Drill System can acquire powdered rock samples from up to 5 cm inside the surface of a rock. This system is part of the Sample Acquisition, Processing and Handling subsystem. ——— Philae's Sample Drill and Distribution system includes an integrated drill, sampler tool, and a carousel designed to collect soil samples at depths of up to 230 mm.
Asteroid sample return (EEV)	Hayabusa (Japan)	Entry capsule with a container designed to carry samples from the asteroid to Earth and enter the atmosphere a velocity of up to 12 km/s.
Rendezvous with small body	Rosetta (ESA) ——— Hayabusa (JAXA)	The Rosetta mission soft-landed its Philae probe on comet 67P/Churyumov-Gerasimenko – the first comet landing in history. ——— Hayabusa performed "touch-and-go" landing on asteroid Itokawa.

Lessons From Previous Sample Return Missions

Storage / Quarantine / Curation

- No quarantine or planetary protection since Apollo

Preliminary Examination

- Detailed investigation flow based on sample suite

Sample Return Facility

- sets expectation for level of technology found behind containment

Technical Support

- staffing and institutional needs

Planetary Protection Considerations

- MSR campaign will not be optimized for extant life detection
- Returned samples must still be treated as though they may contain life
- Need to balance desires of science community with planetary protection requirements

3. MSR Campaign Architecture and Implementation

Focus Areas (Engineering)

"Propose a baseline implementation approach for MSR… identify[ing] critical challenges and opportunities."

(1) IMPLEMENTATION

- *What is the overall campaign architecture?*

(2) TECHNOLOGIES

- *What technologies are required to implement it?*

(3) TIMELINE

- *When can it be implemented?*

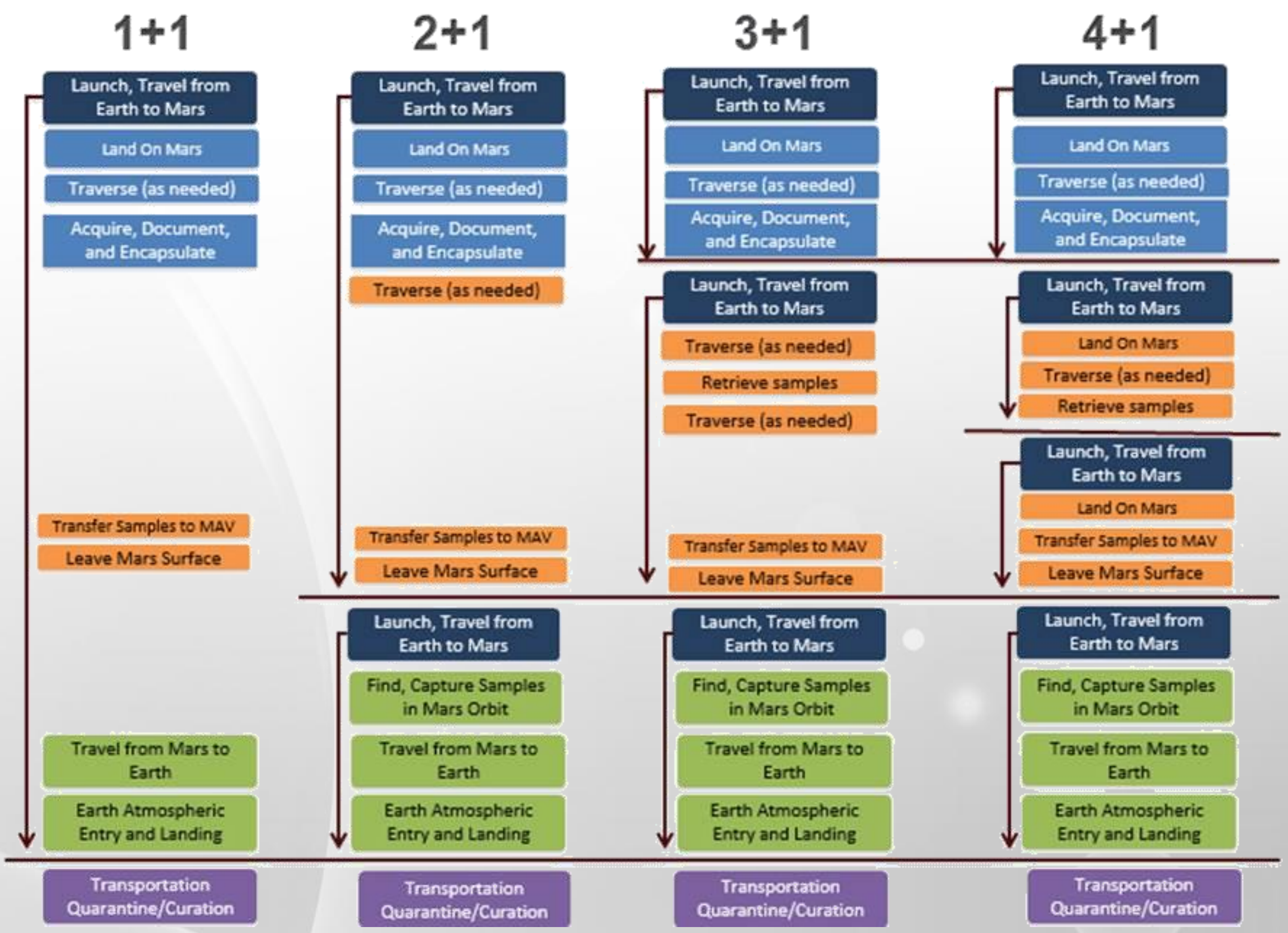
(4) CAMPAIGN MANAGEMENT

- *How can it be coordinated?*

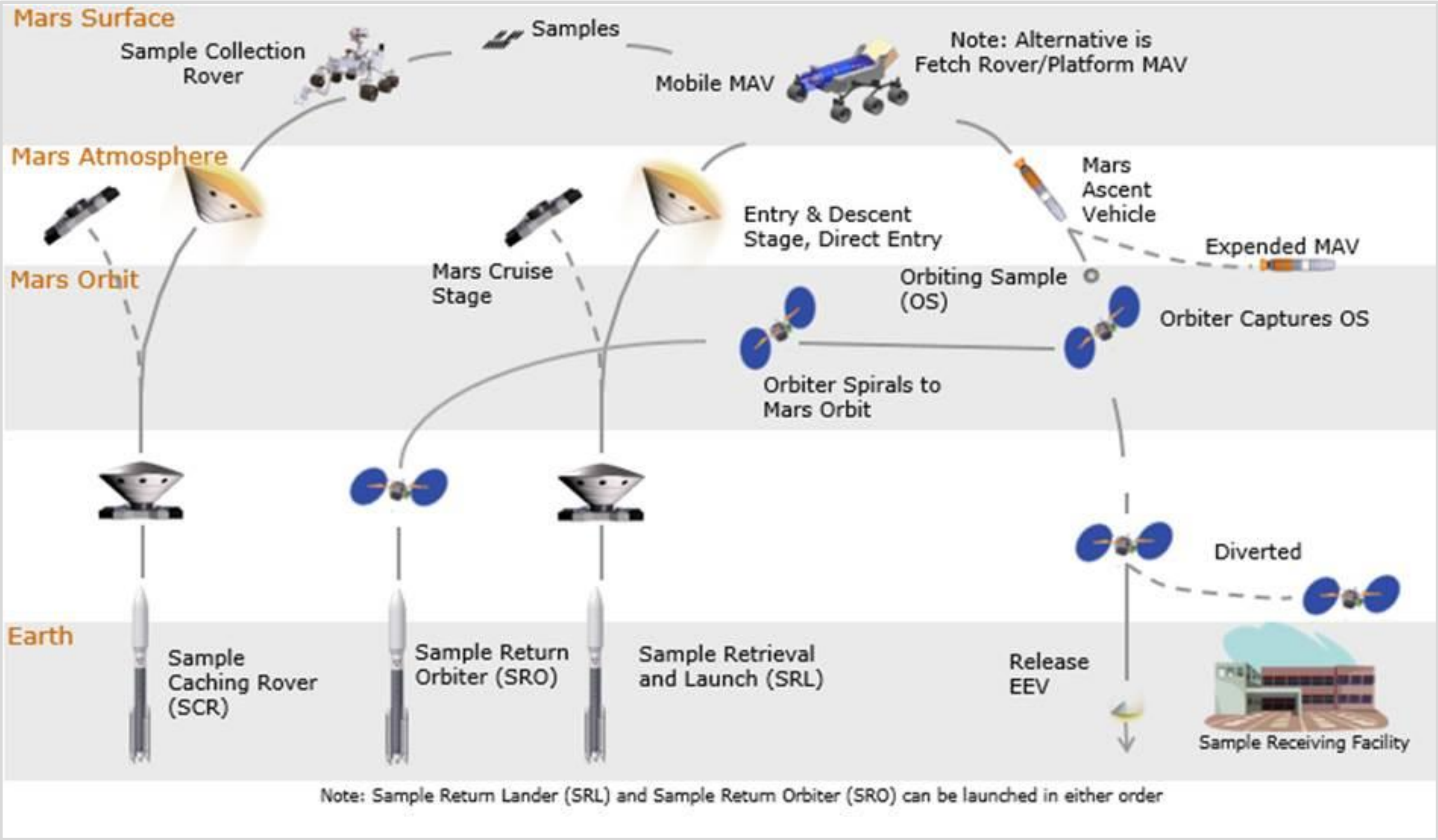
MSR Baseline Requirements Affecting Engineering

- **CR-1**
  - MSR shall collect samples of rock, granular materials (regolith, dust) from various regions of scientific interest, and atmospheric gas.
- **CR-2**
  - MSR shall collect in-situ information for sample selection and establishment of its geological context.
- **CR-3**
  - MSR shall return to Earth a minimum of 500 g sample mass.
- **CR-4**
  - MSR shall maintain the scientific integrity of samples from collection on Mars through containment on Earth.
- **CR-5**
  - All MSR flight and ground elements shall meet planetary protection requirements for Category V, restricted Earth return, established by COSPAR (see Appendix 6.2).

MSR Architectural Options



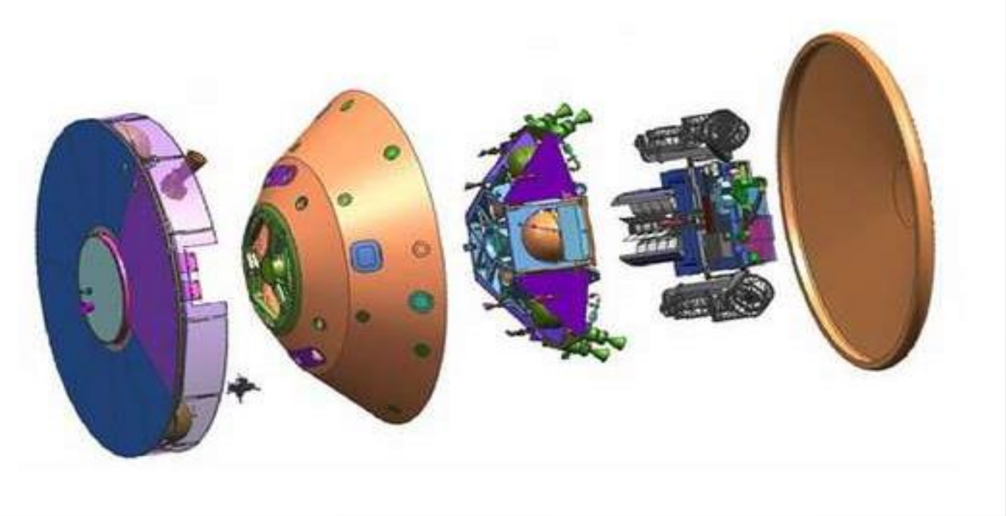
Mars Sample Return Reference Architecture (3+1)

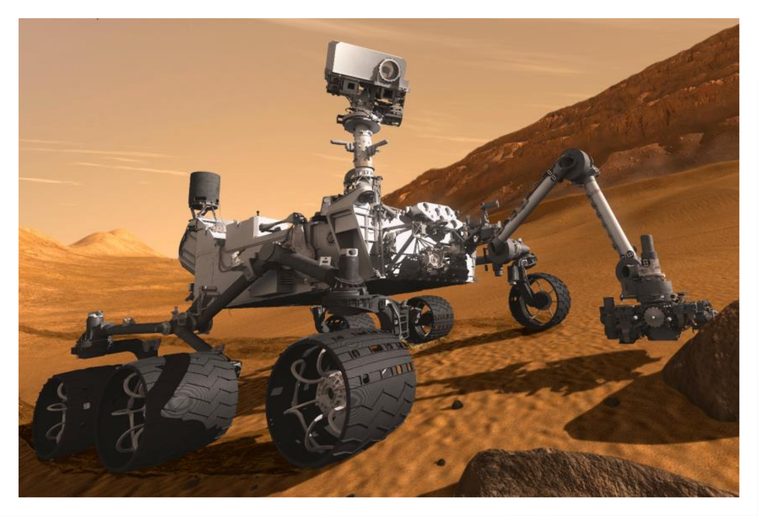


MSR Architecture Reference - SCR

Sample Caching Rover (SCR) element:

- Earth-Mars cruise stage
- Entry-descent-landing (EDL) system
- mobile rover with a science & sampling payload
- cache transfer assembly (CTA)

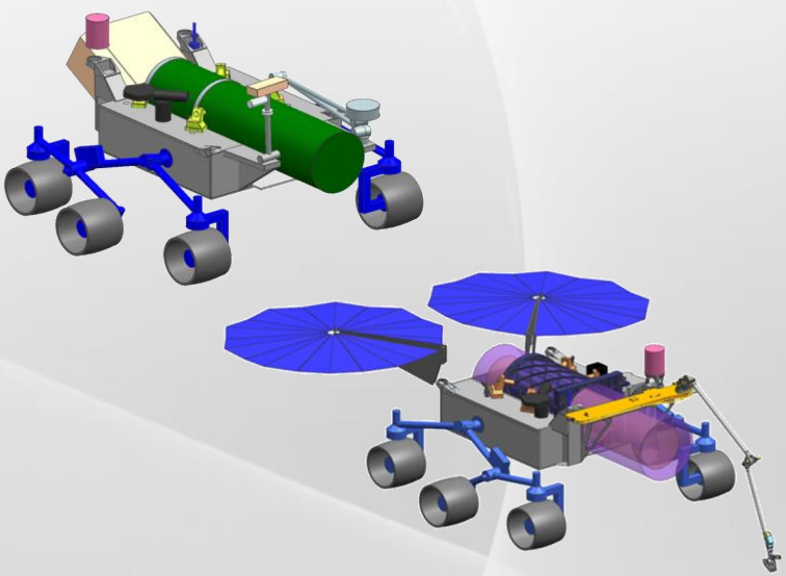


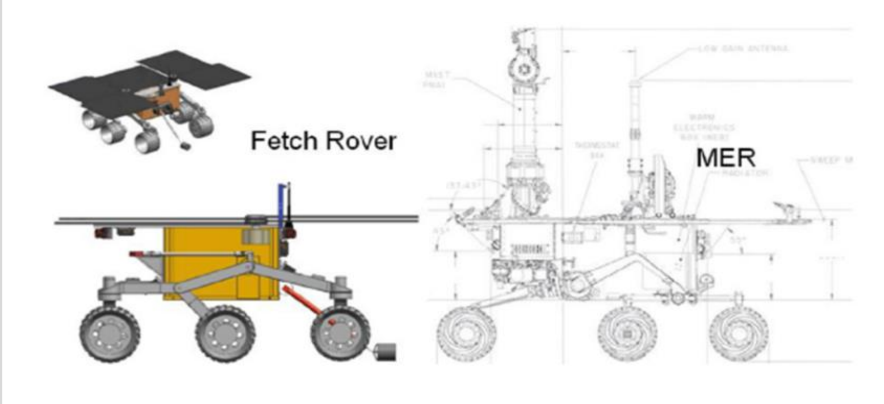


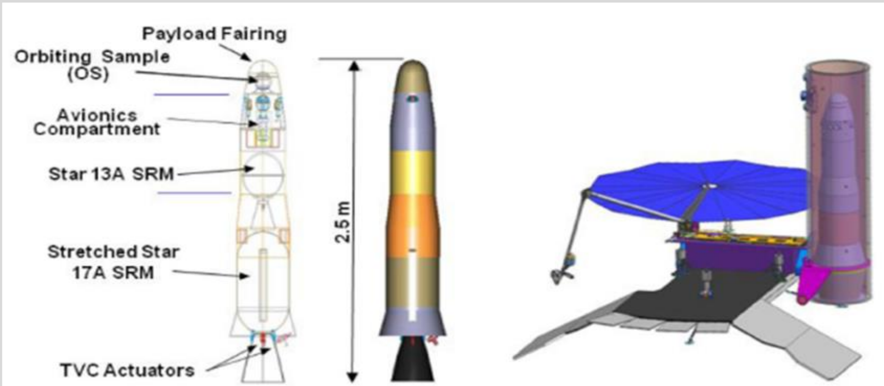
MSR Architecture reference - SRL

Sample Retrieval & Launch (SRL) element:

- Earth-Mars cruise stage
- EDL system
- Sample retrieval system
- Mars ascent vehicle (MAV)
- Orbiting Sample container (OS)





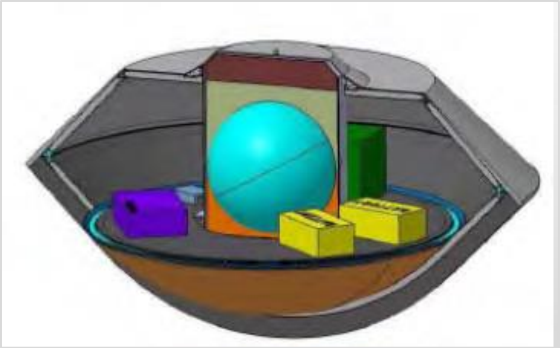


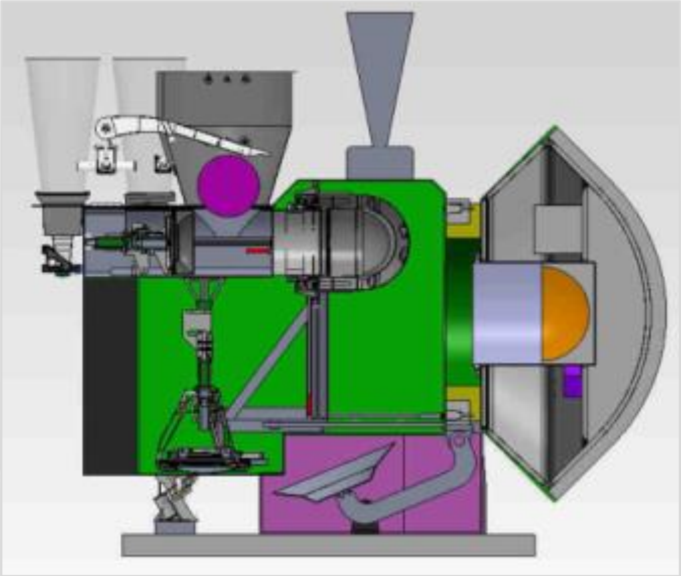
MSR Architecture reference - SRO

Sample Return Orbiter (SRO) element:

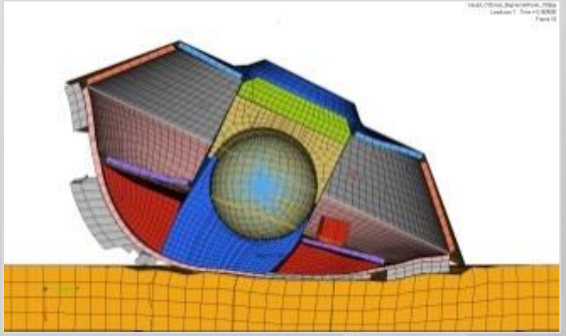
- Orbiter with a rendezvous sensor suite and a capture mechanism
- Bio-Containment system
- Earth Re-entry Capsule (ERC)
- Propulsion module

Re-entry capsule



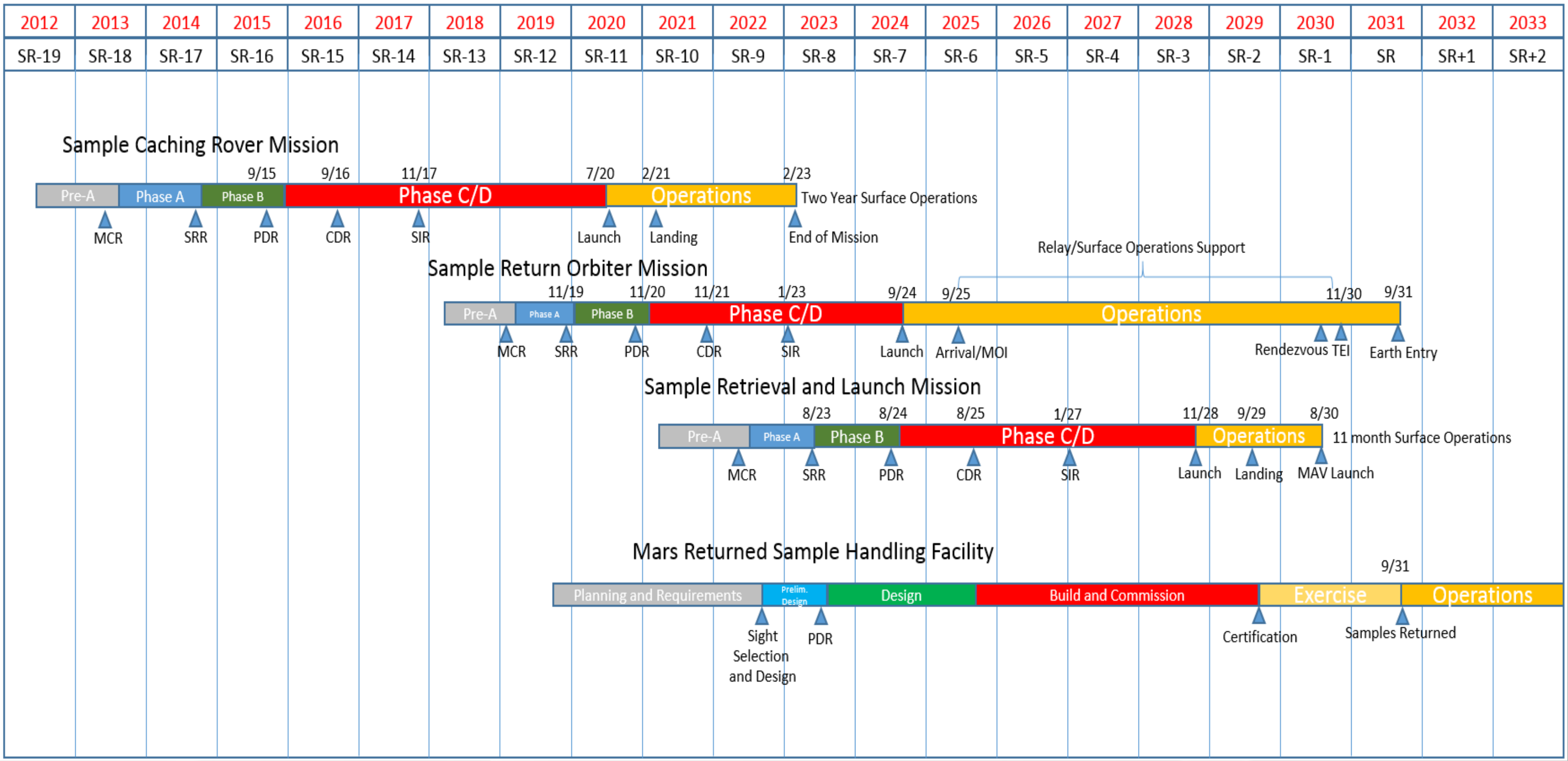


Sample handling & biosealing



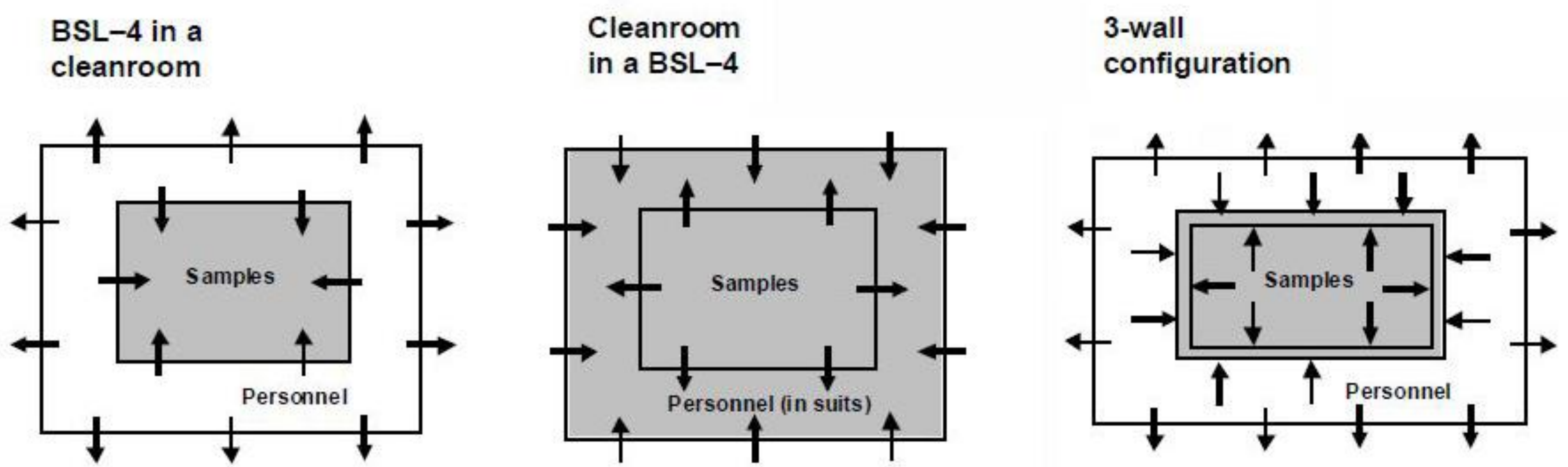
ERC hard landing

Notional Campaign Timeline (2031 Sample Return)



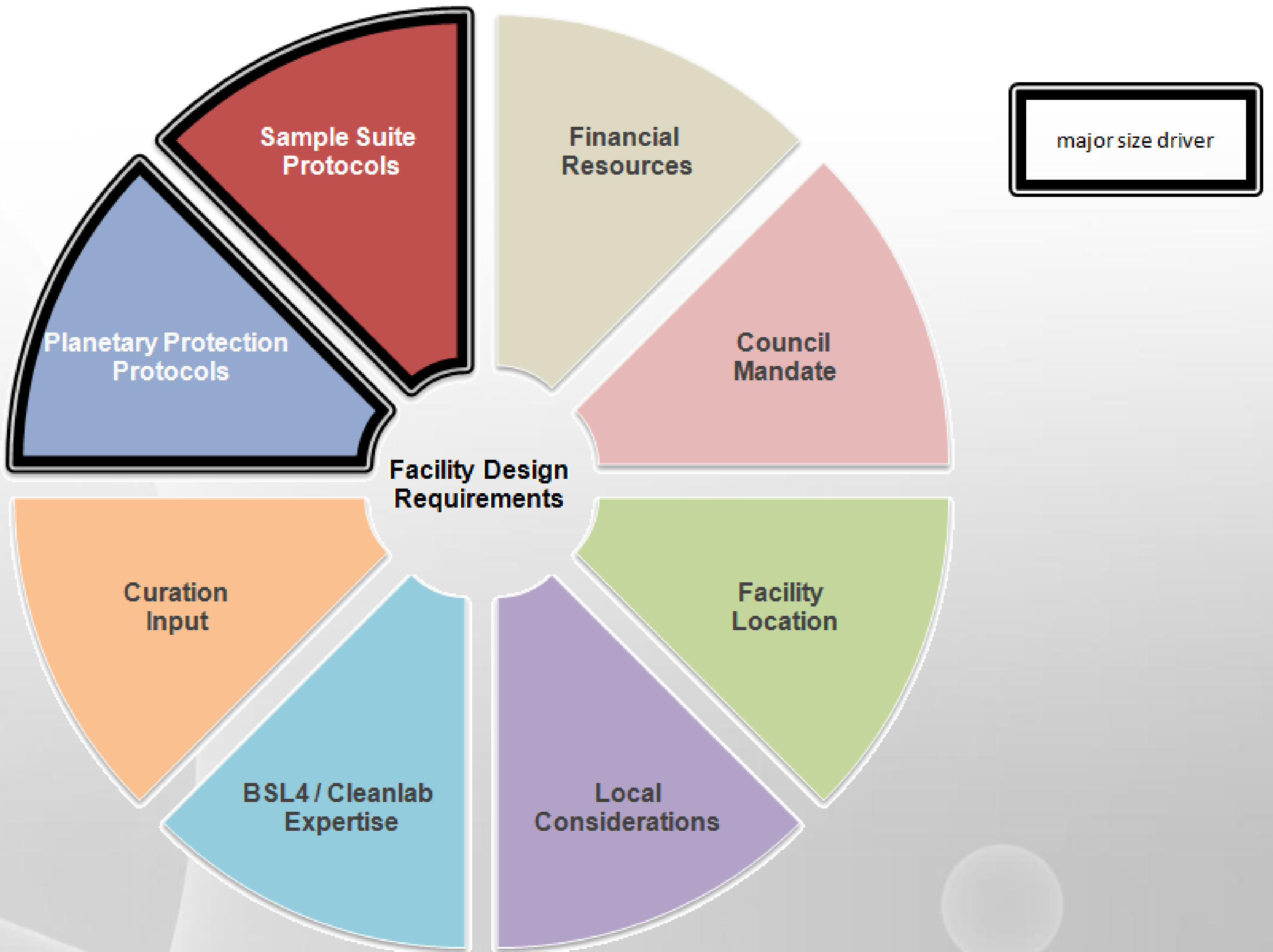
Sample Receiving Facility: Basic Requirements

Major challenge: Must combine elements of positive- and negative-pressure environments



Rummel et al. (2002)

SRF Design Considerations



SRF: Development Timeline

2019

2031

YEAR	EVENTS
Year X:	Funding is in place; negotiate staffing of Institute Council and initiate searches for SAB, BCB, and PAB members
Year X+1:	Executive positions (Institute Council, SAB, BCB, and PAB) in place; initiate search for Facility Director
Year X+1.5:	Facility Director in place; initiate searches for Science, Curation and Safety Heads
Year X+2:	Leadership team in place; initiate searches for key personnel required for SRF design (multiple positions)
Year X+3:	Begin design of SRF, including preparation of draft protocols for preliminary examination of samples, needed to design facility (allow two years based on Lunar Receiving Laboratory experience). Site selection process commences for the SRF
Year X+5:	SRF design in place
Year X+6:	Begin SRF construction (allow two years, based on BSL-4 experience, but may be less or more)
Year X+8:	Begin SRF analytical laboratories construction (allow one year); begin analytical instrument selection process (this should be left as late as possible to ensure cutting edge facility)
Year X+9:	Install and carry out specifications testing on laboratory instrumentation
Year X+9.5:	Carry out verification and validation of facility and laboratories
Year X+10:	SRF completed and "ready" to receive samples; carry out operational readiness testing
Year X+12:	Mars samples delivered to SRF

4. Sample Science Management Plan

Focus Areas

Assuming we are returning samples safely from Mars, how are we going to deal with them when we get them back?

(1) ORGANIZATION	**(2) SCIENCE MANAGMENT**
Outlines general institute structure and needs for facilities	*Defines scientific leadership, institute membership and funding*

(3) SCIENCE OPERATIONS & DATA	**(4) CURATION PLAN**
Sets plan for sample access and scientific investigation	*Focuses on sample handling, storage, and distribution*

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What are its key functions?

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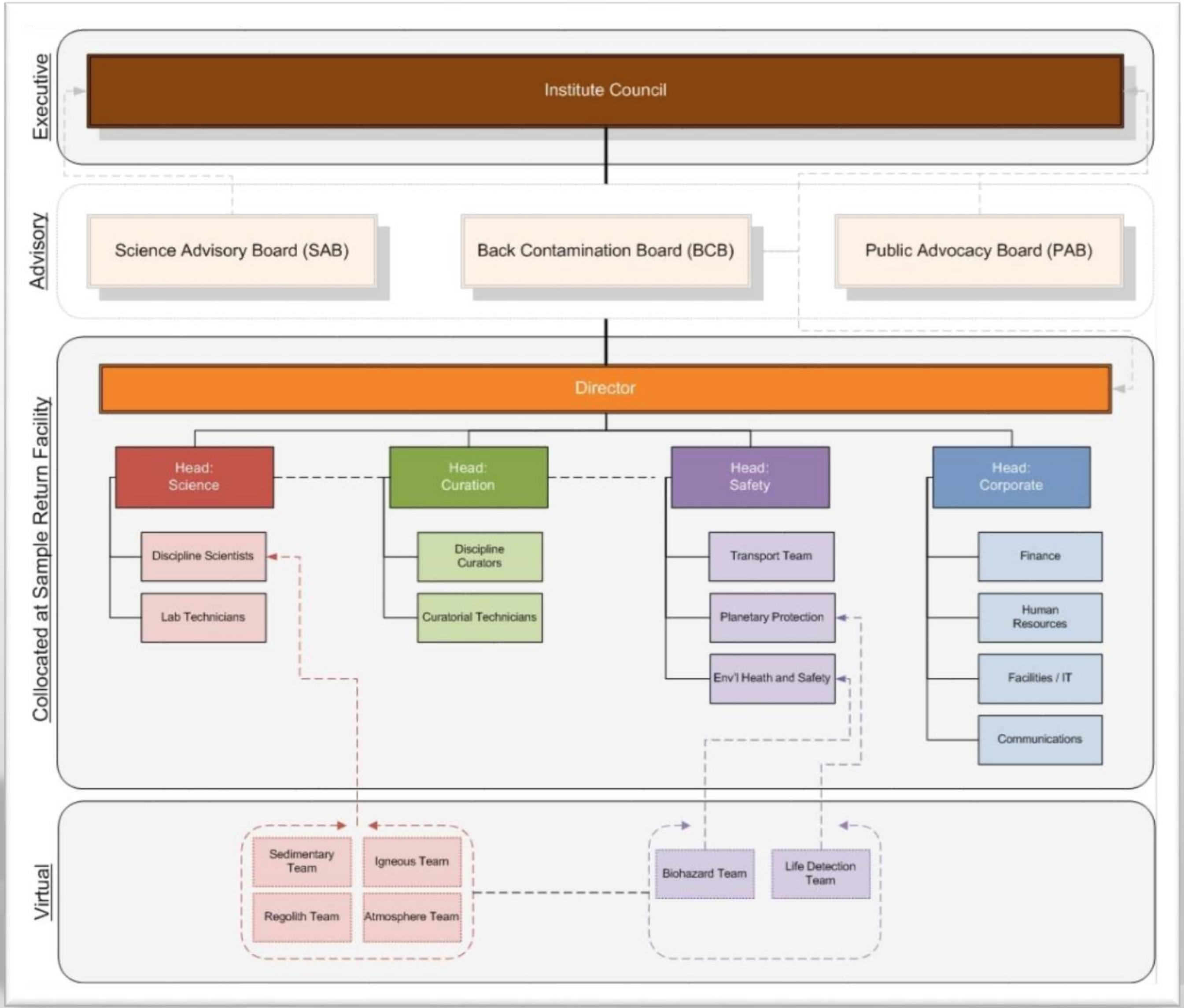
Proposed Organizational Structure



Proposed Organizational Structure

Executive

Key Stakeholders: agency / government representation

Advisory

Oversight: independent bodies

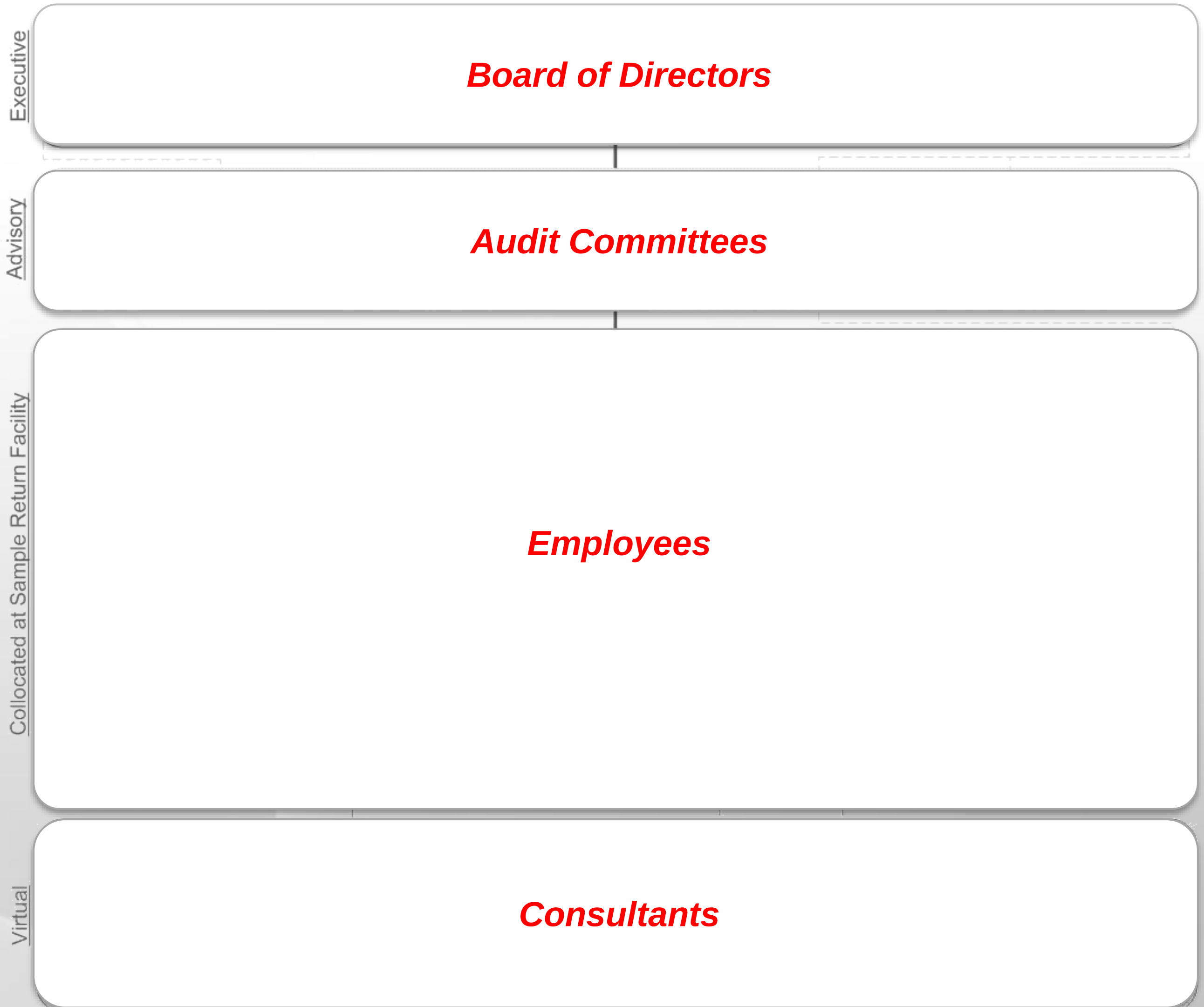
Collocated at Sample Return Facility

On-Site Technical Branches: institute employees

Virtual

Distributed Institute Teams: international experts

Proposed Organizational Structure



Opportunities for Science Participation

	Sample Collection	Post-Collection / Pre-Return	Preliminary Examination	On-Site Investigations	Off-Site Investigations
Potential Role	Sample team	Suite-based virtual team	Mars Sample Preliminary Examination Team (MSPET)	Guest scientist	External scientist
Location	Distributed	Distributed	At SRF	At SRF	Distributed
Selection Process	Competed	Competed	Competed & appointed	Competed	Competed
Activities	Select which samples are collected	Develop sample analysis and handling protocols	Conduct initial physical and geochemical characterization	Perform hypothesis-driven research within the SRF	Perform hypothesis-driven research at home institution

Objective: Ensure that there are several "entry points" for community members to become participants in the process

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Preliminary Sample Analysis

Initial analysis will follow a pre-designated and peer-reviewed protocol

- *this should be our starting place*

BSL-4 unlike most others – *no bugs out OR in*

- best model may be forensic science facilities

SCF instrumentation chosen ≥2 years in advance limiting ability to carry out state-of-the-art preliminary examination

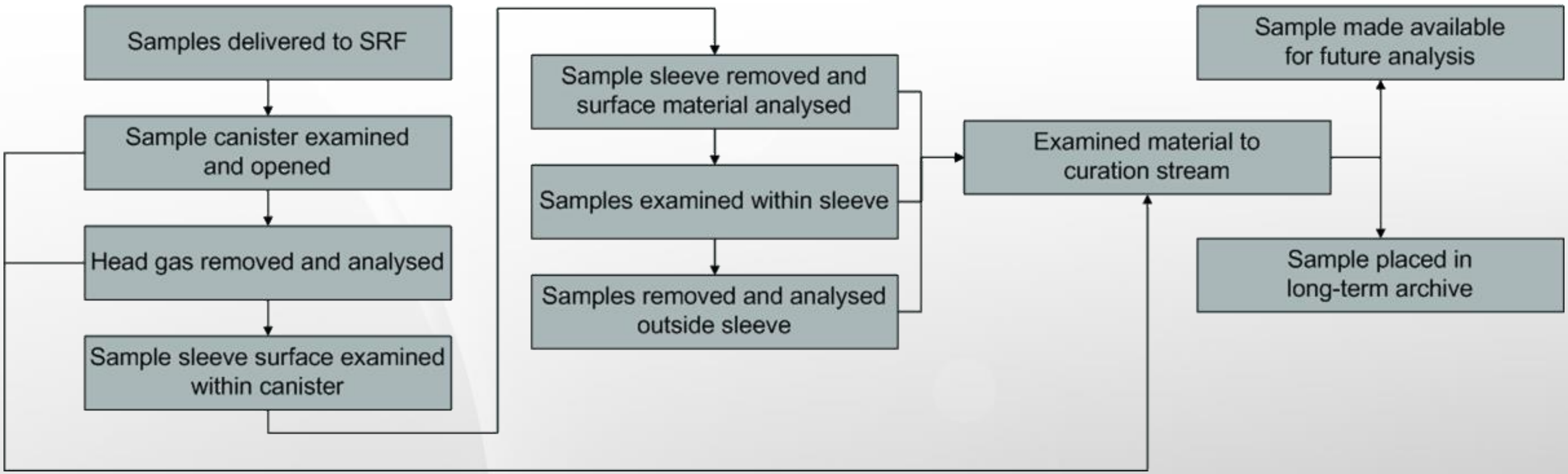
- Adaptability of facility design/infrastructure will be very important

Preliminary analyses carried out in SCF will need to satisfy both Planetary Protection and Science needs

- PP and preliminary science investigations are highly complementary and inform each other

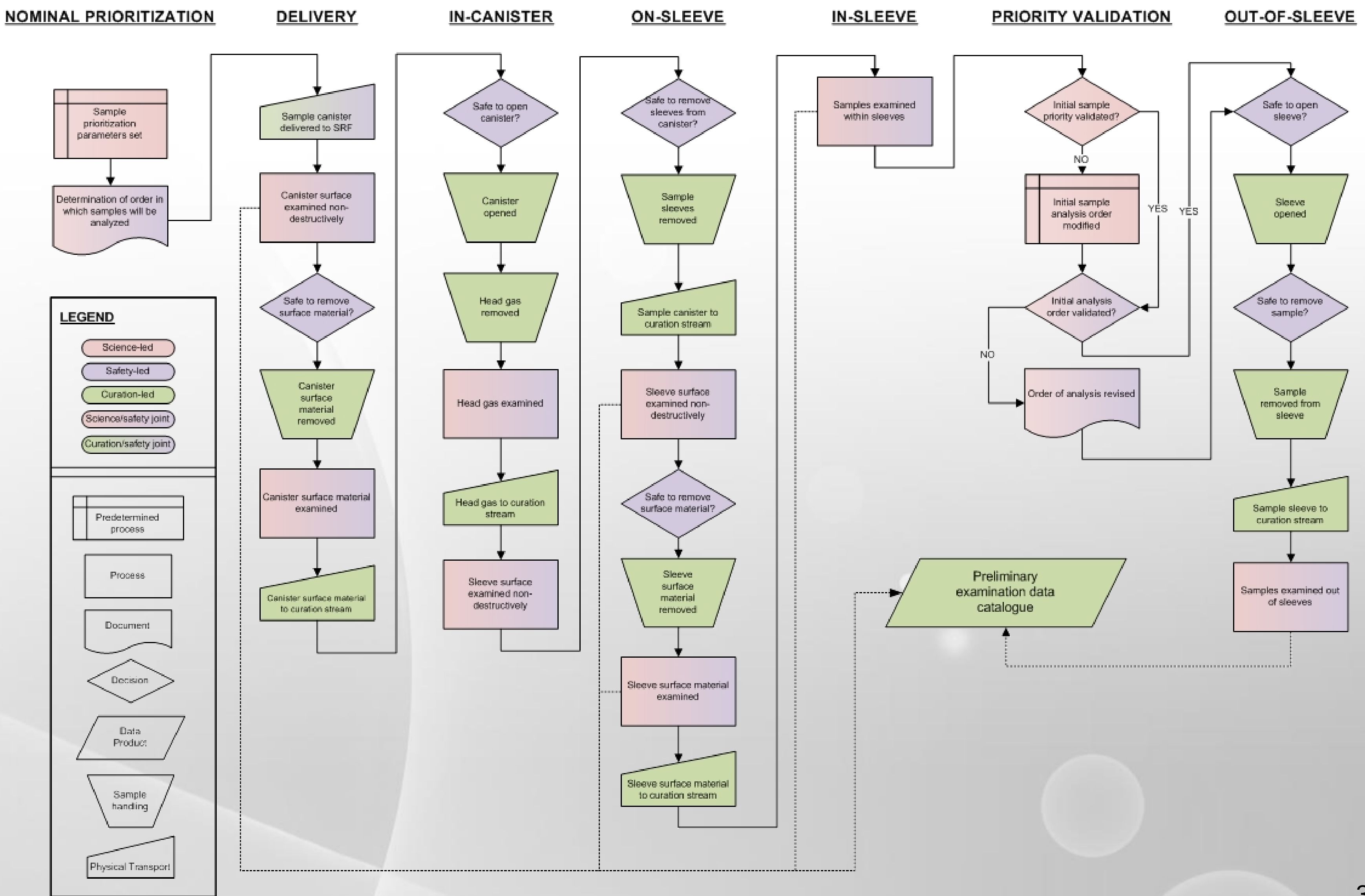
Preliminary Sample Analysis (General Flow)

Hardware **Samples** **Distribution / Archiving**



- Conducted within containment at SCF; initially protocol-dominated
- SCF staff-dominated (MSPET), with some incorporation of Guest / External scientists

Preliminary Sample Analysis (Detailed Flow)



Science Access and Allocation: Process

Sample Allocation Assessment: a two-stage process

- Stage 1 – Sample Availability Determination
  - Enquiries about sample availability – review focuses on availability, lab verification and validation, management plan, consistency with published sample strategy plan, etc.
- Stage 2 – Formal Sample Request
  - formal requests with evidence of funding, and peer review, updates from enquiry, etc. – review focuses on consistency with initial enquiry, changed circumstances, etc. – philosophy is that if all thing went according to plan, samples will be made available

Sample Allocation Structure

- Sample Allocation Committees (SAC)
  - one for each sample “suite” (e.g., SAC-Ign, SAC-Sed, etc.) – approves normal requests – composed of Discipline Curator, Discipline Staff Scientist, Specialist scientists
- Sample Allocation Review Board (SARB)
  - deal with appeals, special requests – composed of Curator, Science Director, Outside scientists

Increased Complexity of Sample Curation

EG. Apollo Samples

Within Facility?

Yes	No

Will require dedicated, permanent curatorial staff

Mars Samples

Within Facility?

Within Containment?

Yes	No
No	Yes

Sample Tracking and Routing

Samples will need to be tracked within, leaving, and re-entering the SCF

- Curation and tracking of “destroyed” or “altered” samples
- Avoidance of sample cross-contamination
- “Waste” samples still have scientific value
- Complexity of sub-sample multiplication
    - One sample goes out → TBD number of samples are returned
    - Samples are returned in non-original state, have been studied at different labs etc.
- Ensuring external laboratories maintain sample handling and curatorial protocols e.g. cleanliness, documentation

We have developed a high-level routing protocol for samples going <u>OUT</u> of the SCF and returning <u>IN</u> to the SCF

Sterilization Techniques

Assumption that samples are hazardous

- Until proven to be non-hazardous, samples must be rendered safe by some sterilisation method in order to be released from containment

Two key issues need to be addressed

- 1) what technique(s) should be used?
- 2) which samples/how much sample should be sterilised?

Some previous work has been carried out in this area → investigation of gamma-ray effects on rock, minerals (Allen et al. JGR, 1999)

- Unclear how γ-ray sterilisation could affect key science objectives e.g. analyses of organics, isotope geochemistry
- Other sterilisation methods are available, all have advantages and disadvantages
- Techniques for sterilisation of samples is a key issue and requires further attention
- Important implications for SCF requirements going forward

Archive/Posterity Samples

iMARS Phase I recommendation of 40 % ‘archive’ sample remains valid

- Which 40 % is chosen is an open topic
  - 40% of everything?, 40 % of certain samples?
- Archive sampling recommendations will be defined before and during sample acquisition and preliminary investigation
- Should some samples remained unopened (‘pristine’)?
  - As above → which, how many?
  - ‘Blank’ samples will be important in this context

5. Conclusions and Recommendations

Summary & Conclusions

Programmatics

- MSR requires extensive international collaboration
- Successful partnership relies on early and binding long-term commitments

Technology

- 10+ years from conception to operational readiness
- 3+1 architecture provides flexibility in responsibilities and failure mitigation

Sample Management

- Science, safety, and curation must be considered together
- Key requirements and protocols require formal definition

Key Recommendations

1. Planetary Protection Protocol

- should be produced as soon as possible
- international task force should be created

2. Sterilization Protocol

- methods and doses required to adequately sterilise samples returned from Mars must be defined
- international working group should be tasked, or individual agencies should fund extensive research

3. Institute and SRF require 12 year lead time

- stepwise development will be required

4. MAV and "Break-the-Chain" require focused development

- technology has advanced significantly, but still a few steps to go…